Q/V/W Band Study

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Tasks

- Current Status of QVW Band Propagation Measurements and Modeling
- Propagation Measurements System Design Requirements
- Define Additional Modeling
- NGSO vs. GSO Measurements

Introduction

- Literature search of Q/V/W band systems and experiments
- Atmospheric effects predictions and the validation in bands above 35 GHz
- Specification of ground and space segments for a atmospheric measurement campaign

Why Collect Data at QVW Bands

- FCC filings are already piling up for these bands
- Larger bandwidths will be possible at these frequencies
- Frequency Scaling Models are not good enough
  - sometimes it works well, sometimes it doesn't
  - works for small frequency differences, but fails for large differences due to size of atmospheric attenuators
  - Models are mostly empirical

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Propagation Considerations

- **Propagation Impairments**
  - Sources
  - Impairments
  - Other Considerations
- **Propagation Models**
  - For each effect
  - Validation
- **Experiments**
  - ITALSAT
  - STENTOR

Sources of Propagation Impairments

- **Atmospheric Sources of Impairments**
  - Precipitation
    - Rain, Snow, Sleet, and Hail
  - Suspended Water
    - Hydrosols, Ice, Fog, and Melting Layer
  - Gaseous Constituents
    - Water Vapor and Oxygen
  - Refractive Index
    - Turbulence, Multipath, and Ducting
- **Non Atmospheric Sources of Impairments**
  - Wet Antenna, Radome, and Feed
  - Dust, Sand, and Ash
  - Bugs (W-Band)
  - Topography (Diversity & Site Planning)
  - Aerosols

Impacts to Signals

- **Signal Degradations**
  - Attenuation
  - Depolarization
  - Dispersion
  - Scintillation

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- **Other Considerations**
  - Dynamics
  - Combined Effects (Validation at higher frequencies)
  - Particle Sizes and Shapes
  - Availability/Margin
  - Multiple Site Operation

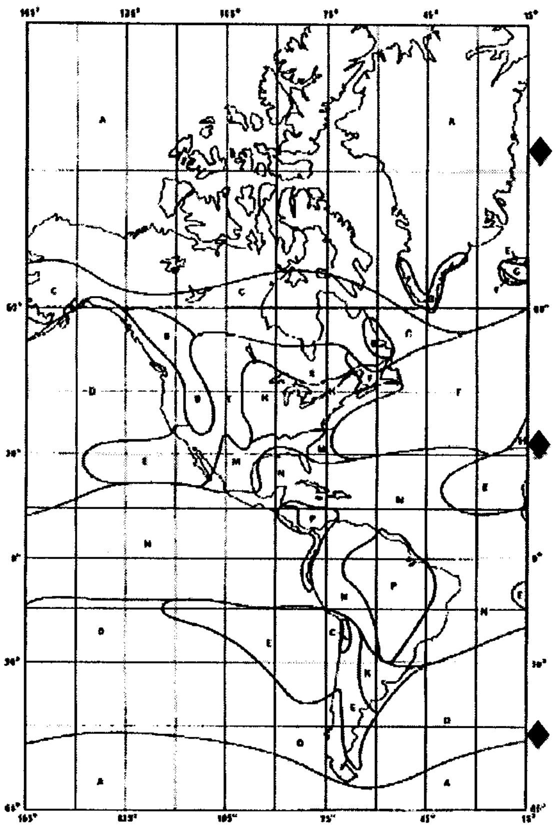
Model Validation Overview

- Earth-Space Propagation Models Have Not Been Widely Validated at Frequencies Above about 30 GHz.
- Small amount of Validation Available (ITALSAT) for Frequencies up to 49.5 GHz
- Best Approach Use Models Heavily Based in Theory Especially for Frequency Dependent Terms

Rain Attenuation Modeling

- **Attenuation**
  - Several Models in Wide Use
    - DAH - Empirical; will be new ITU-R Model in September
    - ExCell - Theoretical, based on radar cross sections of rain cells
    - ITU-R - Empirical; performs best in temperate, mid-latitudes
    - Global & Two Component - Semi empirical; each will work great in some locations, but fall apart in others
  - At Least 10 Other Models Also Available
  - While ACTS and ITALSAT data indicate models do not experience any dramatic degradation in performance up to 50 GHz,very little data exists for frequencies above 35GHz
    - ACTS is below Q/V/W Bands
    - ITALSAT measurements in temperate mid latitudes only
- **Rain Rate Maps: Several Available**
  - Crane – ITU-R (Old Rec 838-1) – ITU-R (New Rec 838-2)

ITU-R Rain Rate Maps



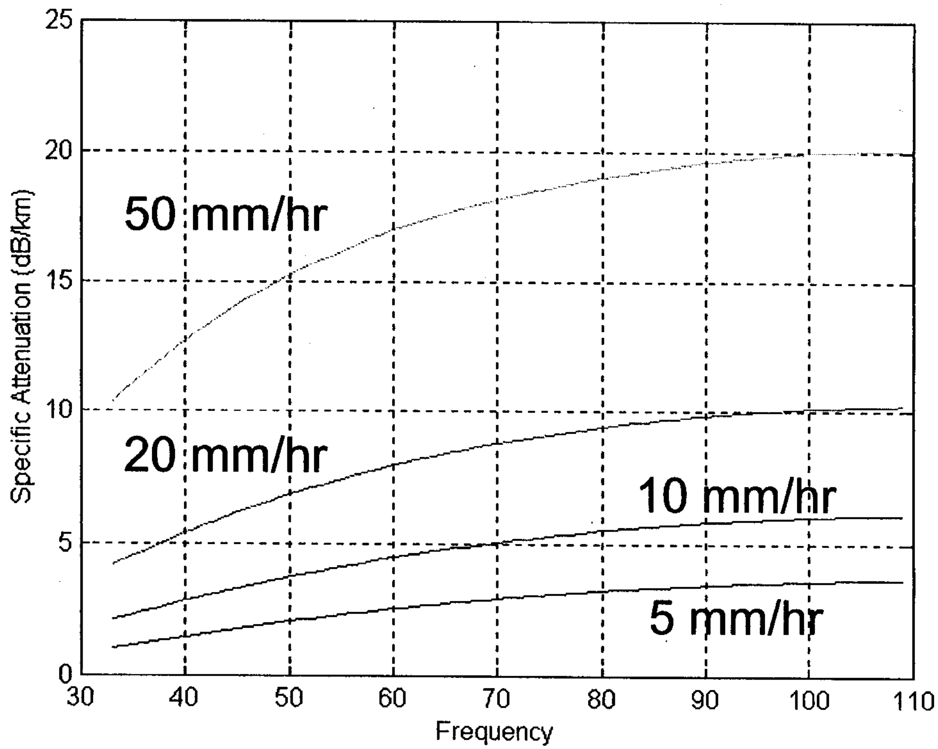
Before

- 15 old rain zones are replaced by 28,920 new rain Zones
- Based on 15 years of global data compiled every 3 hours by European Center for Medium range Weather Forecast (ECMWF)
- Complete distributions of rain rate are available globally over a 1.5° grid with a 2-D interpolation routine
- RMS Error of rain rate distribution reduced from ~35% to ~25%
- Greatest Improvement is in the Tropics

After

Severity of Rain at Q/V/W Bands

- **Theoretical Prediction:**
  - Standard α/β Model
  - Attenuation increases ~2-2.5 times between 33 and 110 GHz
- **Other Particles (e.g. hail, sleet, snow) will attenuate and depolarize differently**
- **As wavelengths approach the size of these particles, sizes, shapes, and ice to water ratio become more important**



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Rain Depolarization Modeling

- **Chu Semi-Empirical Model; Validated to ~ 30 GHz**

$$XPD = 11.5 + 20 \cdot \log(f) - 20 \cdot \log(A) - 40 \cdot \log(\cos(\theta))$$
$$- 10 \cdot \log\left[\frac{1}{2} \cdot (1 - 0.978 \cdot \cos(4\tau))\right] - 0.075 \cdot A \cdot \cos^2(\theta) \cdot \cos(2\tau)$$

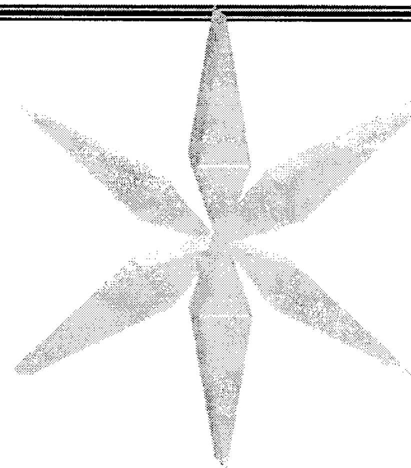
- **ITU-R Model; Empirical - Validated with ITALSAT to ~ 55 GHz**

$$XPD = 30 \cdot \log(f) - 22.6 \cdot \log(A) - 10 \cdot \log[1 - 0.484(1 + \cos 4\tau)]$$
$$- 40 \cdot \log(\cos(\theta)) + 0.0052 \cdot \sigma^2$$

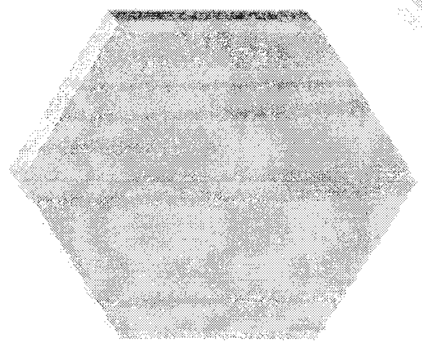
- **Using either model, XPD improves with frequency for a given attenuation level**
- **Limited when wavelength approximates particle size**

Frozen Precipitation

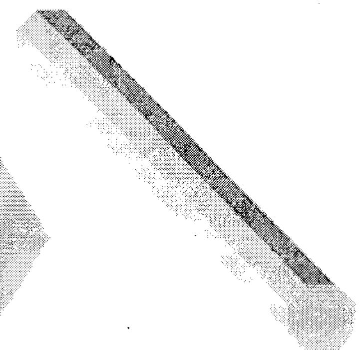
- **Hail**
  - Impact:
    - Attenuates - if coated by water
    - Depolarizes - if not spherical
- **Snow**
  - Impact: Attenuation & Depolarization
    - Depole greatest at low elevation angles
  - Model: Transmission Matrix
    - 43 Different kinds of snow
    - Parameters of interest
      - Shapes (plates or needles)
      - Size distribution
      - Ratio of ice, water, and air
    - Many flakes are aggregates



Dendritic Plate



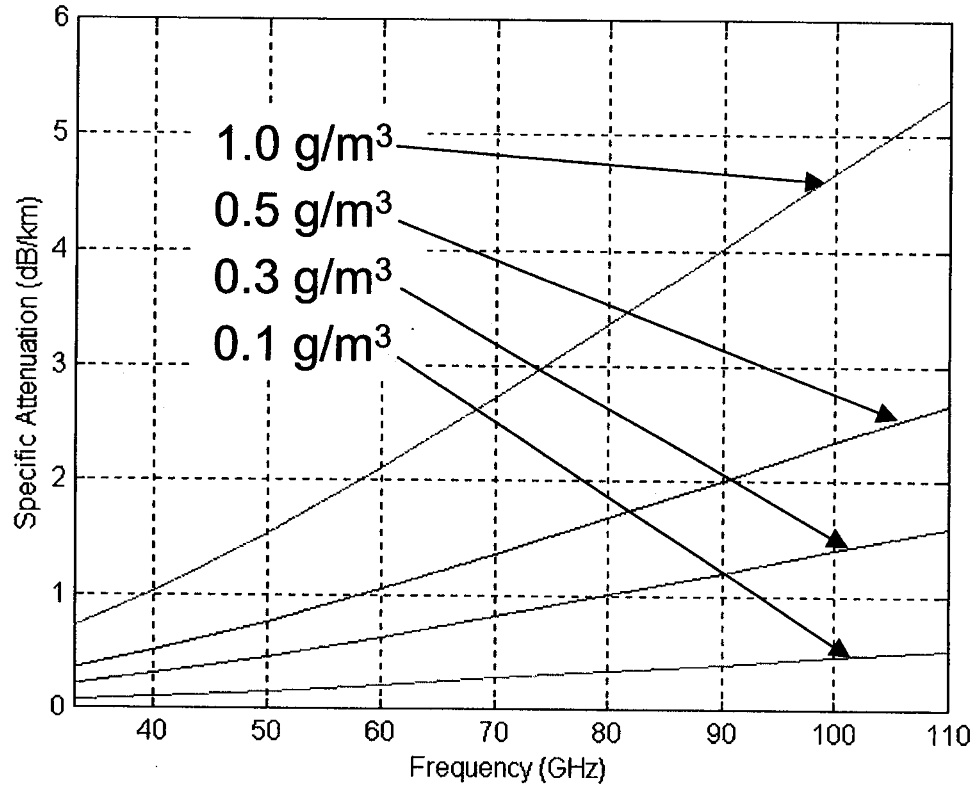
Plate



Needle

Suspended Liquid Particles

- Liquid Water (Clouds)
  - Impact: Attenuation increases monotonically with frequency and linearly with water content
  - Models:
    - Liebe MPM 93; Theoretical - very accurate assuming the structure of the cloud is known
    - ITU-R; Semi-Empirical - "watered down" version of MPM93



- Fog (Low Density Liquid)
  - Same models apply

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Suspended Frozen Particles

- **Ice (Cirrus)**
  - ✶ Impact: Depolarization; some attenuation possible at W Band
  - ✶ Models:
    - ✦ ITU-R; Empirical - statistically adds extra ice depolarization term onto rain depolarization distribution
    - ✦ Frequency Scaling Factors; Based on ITALSAT

$$XPD_2 = XPD_1 - 20 \cdot \log\left(\frac{f_2}{f_1}\right)$$

    - ✦ Scale factor may not be valid beyond ~50 GHz

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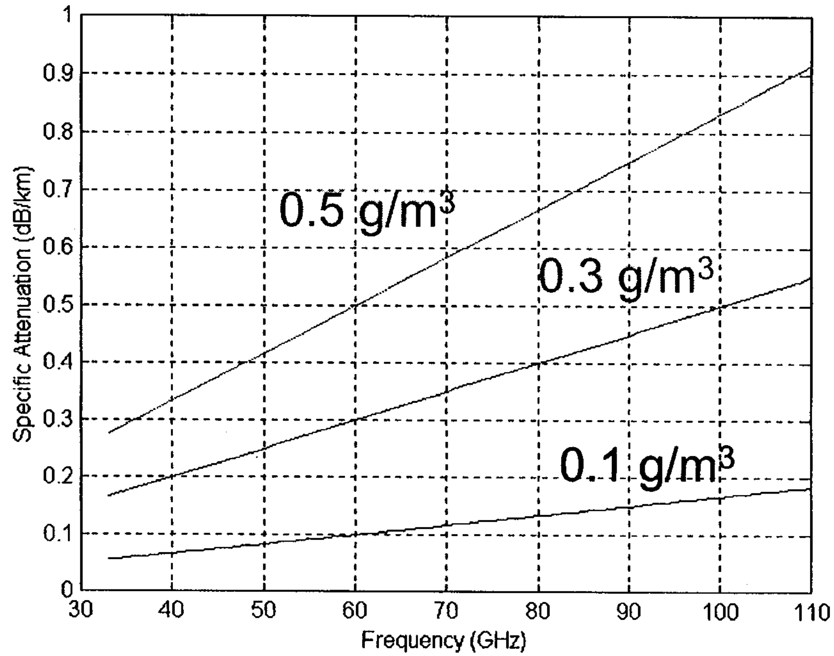
Specific Attenuation of Suspended Ice

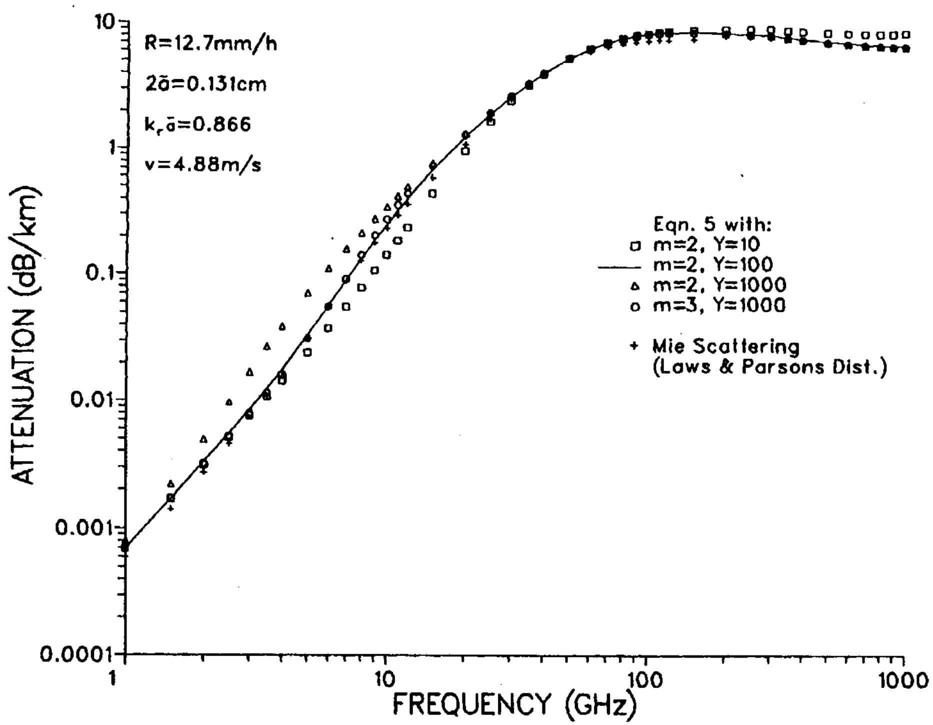


Assumes

- Using Guissard Model
- T=0 °C
- Theoretically valid $3 \le f \le 90$ GHz

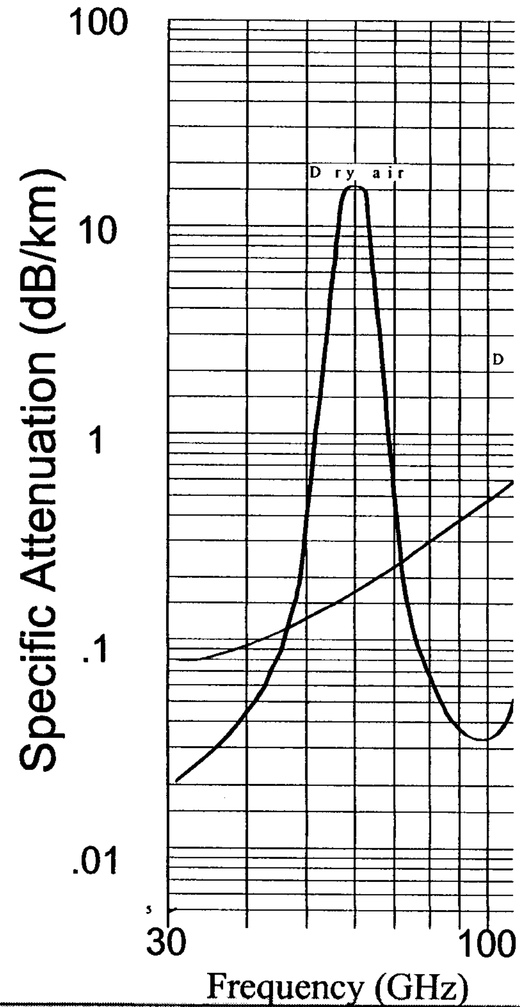
Suspended Melting Particles

- Impact
  - Most impact per particle, but
  - Melting layer is very thin (≤ 0.5 km)
- Models
  - Dissanayake (1997); Empirical
    - not validated beyond 30 GHz
    - specific attenuation at Q/V/W ~ 20 dB/km
  - Kharadli (1988); Theoretical model valid to 1000 GHz,
    - never validated with real data
    - specific attenuation at Q/V/W 1-10 dB/km



Gaseous Components

- **Impact: Attenuation**
  - Q/V/W Band dominated by oxygen absorption lines in the 57 to 63 GHz region.
  - Specific attenuation of water vapor increases by almost an order of magnitude
- **Models:**
  - Liebe MPM 93; Theoretical model - works well if path profiles are understood.
  - ITU-R; Empirical fit to MPM



Dust, Ash, & Sand

- ITU-R Rec. 618-5; "Very little is known about the effects of sand and dust storms on radio signals on slant-paths. Available data indicate that at frequencies below 30 GHz, high particle concentrations and/or high moisture contents are required to produce significant propagation effects."
- Some Data in Mid-east indicates 44 GHz can be attenuated significantly by sand storms
- NM ACTS Site - Observations
  - Sand Storms Occur Regularly Every Spring & Fall
  - Summer 1996 Had a Large Brush Fire with Thick Smoke Along the Link for About Two Weeks
  - No Noticeable Effects Appeared in the Propagation Data

Topography/Microclimatology

- **Important consideration for site planning**
  - ✶ Mountains, rivers, lakes will "steer" weather patterns
  - ✶ Weather fronts may show preferred orientations when passing through an area
- **Local microclimatology may also be used to benefit site diversity by reducing required site separations or number of sites**

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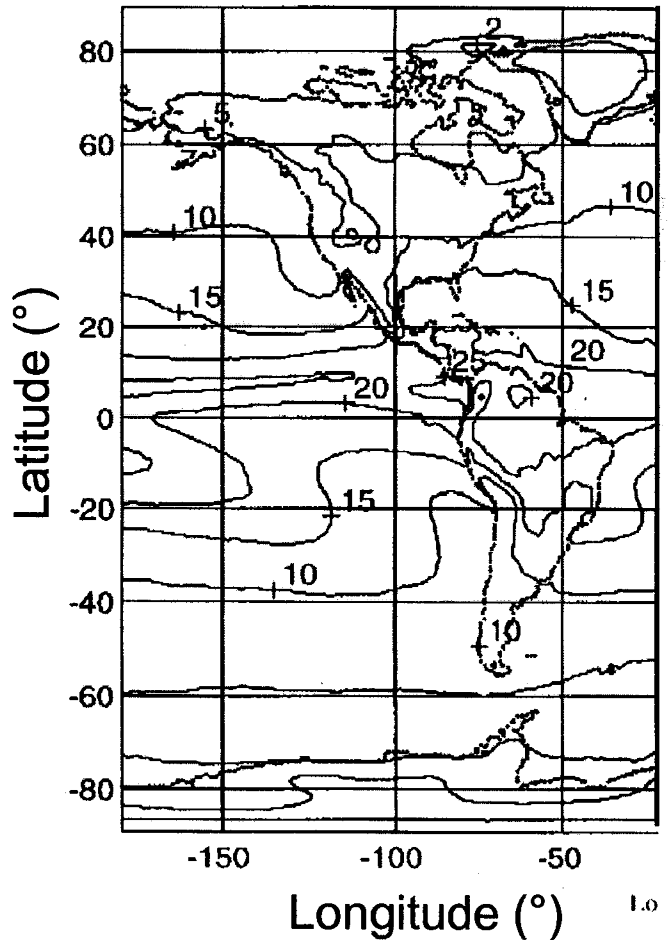
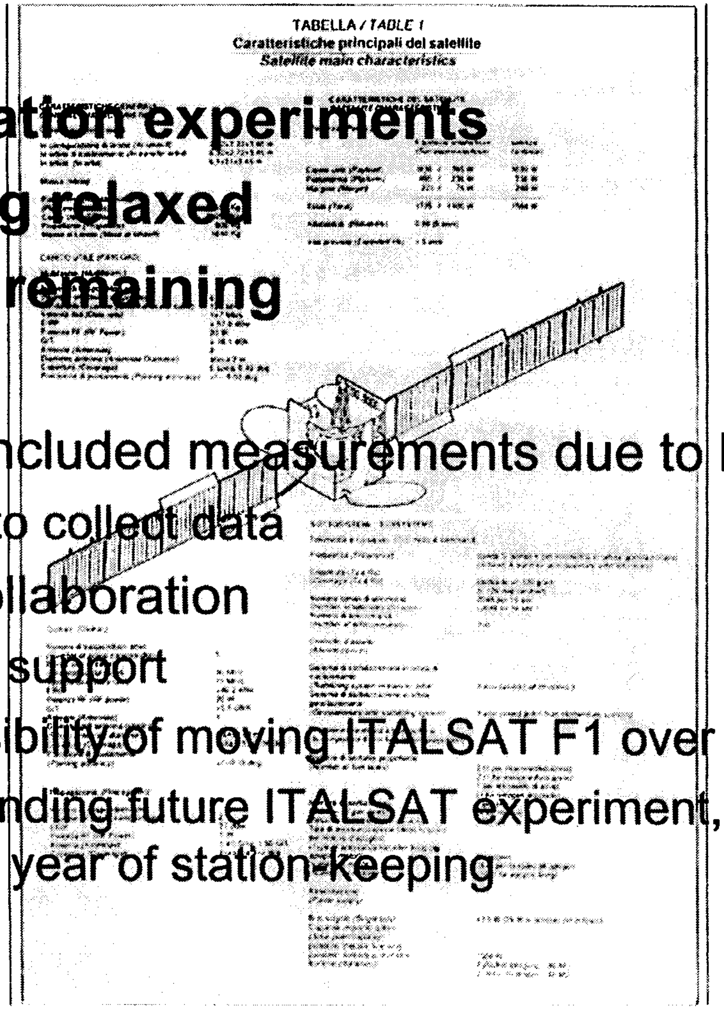
Mean Annual Surface Water Vapor Density (g/m³)



Other Considerations

- **Wet Surface Effects**
  - Impact: Attenuation and depolarization
  - Models:
    - Crane, Acosta, and Horan/Atle
    - Effects will very widely depending on orientation of the antenna and hydrophobicity of the reflector and horn surfaces
- **Bugs**
  - Impact: Some indications of potential depolarization at 80+ GHz
    - Varies with species (i.e. shape and size)
    - internal water content also an issue
  - Models: (?)

ITALSAT



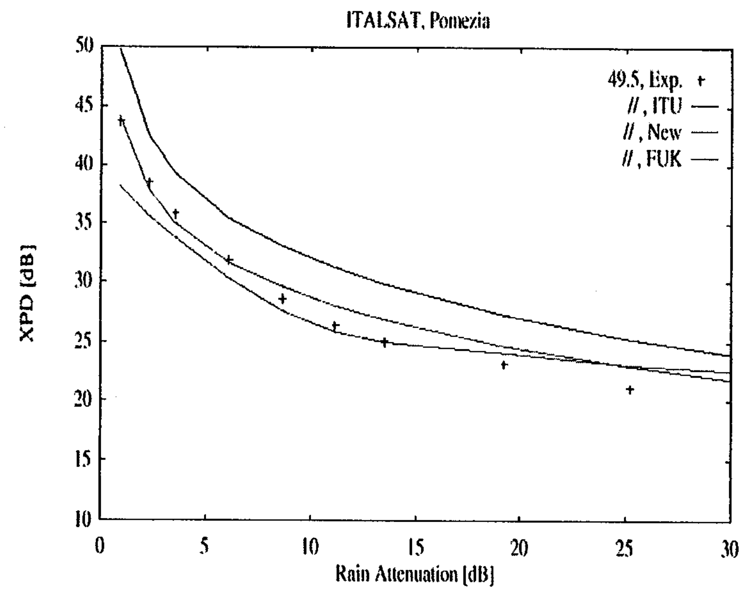
- 9/91 Began propagation experiments
- 2/97 Station-keeping relaxed
- Fours years of fuel remaining
- Budget issues
  - Most sites have concluded measurements due to lack of funds
    - Italians continue to collect data
  - Italians Seeking Collaboration
    - Need operational support
    - Investigating feasibility of moving ITALSAT F1 over Atlantic (15° W)
    - If no interest in funding future ITALSAT experiment, may consider using fuel for one year of station-keeping

ITALSAT Results

- **Attenuation & Depolarization**
  - Measurements in Italy, Nethelands, Norway, Spain, UK
  - All sites have slightly different terminals
- **Additional Measurements of 39.6±0.5 GHz Tones**
- **Most V-Band Data Validated by Scaling 18.7 GHz Beacon**

	18.7 to 39.6	18.7 to 49.5
Measured 1994	2.89	3.78
Measured 1995	3.10	4.01
Measured 1996	2.97	4.20
Measured 1997	3.43	5.00
Average(1994-1997)	3.10	4.25
ITU-R Prediction	3.35	4.47

Frequency Scaling at Spino d'Adda



Summary of Propagation Issues

- Most important atmospheric effects are system dependent.
- Atmospheric effects considered "secondary" at Ka band and below will increase in significance
- Existing Ka band validated models appear to work without significant degradations in performance up to 50 GHz, but they were tested with limited data sets primarily from temperate climate regions
- Empirical scaling of Ka band data may start breaking down beyond 50 GHz
- Theoretical models may provide solutions but better understanding of microphysical properties of the atmosphere is required
- Little validation data available; all comes from temperate, mid-latitude locations.

STENTOR

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- EXPRESS
- Space Segment
- Ground Segment

STENTOR-EXPRESS

- **Experiment Possibilities**
  - Amplitude Measurements at 20.7 & 41.4GHz
  - Differential Amplitude Measurements between 20.7 & 41.4GHz
  - Differential Phase Measurements between 20.7 & 41.4GHz
  - Atmospheric Noise temperature for marginal C/N systems
- **Special Interest**
  - Amplitude Measurements at 41.4GHz
    - very little data exists
    - Tropical data at Ka and Q bands.

STENTOR-Space Segment

Description: *Two Parabolic Reflectors with offset feeds transmitting beacons at 20.7GHz and 41.4GHz*

Waveform:

Coherent beacons at 20.7 & 41.4 GHz

RHCP

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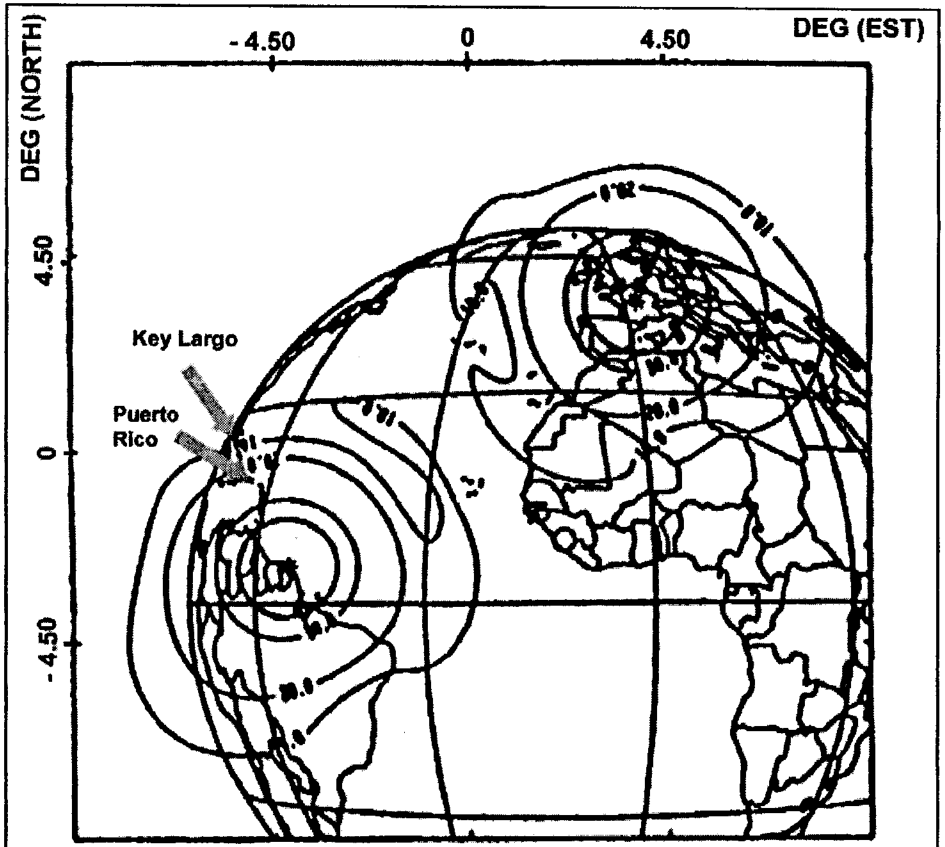
Satellite Antenna Parameters (Guyanese):

Satellite Antenna Parameters	**41.4 GHz**	**20.7 GHz**
Feeder Loss	4.8 dB	7.1 dB
Antenna Input Power	21.7 dBW	18.4 dB
Maxiumum Transmit Ant Gain	34.8 dBi	36.2 dB
Maximum EIRP	26.5 dBW	24.6 dB
Antenna Diameter*	20 cm	45 cm
Antenna Focal Length*	20 cm	36 cm

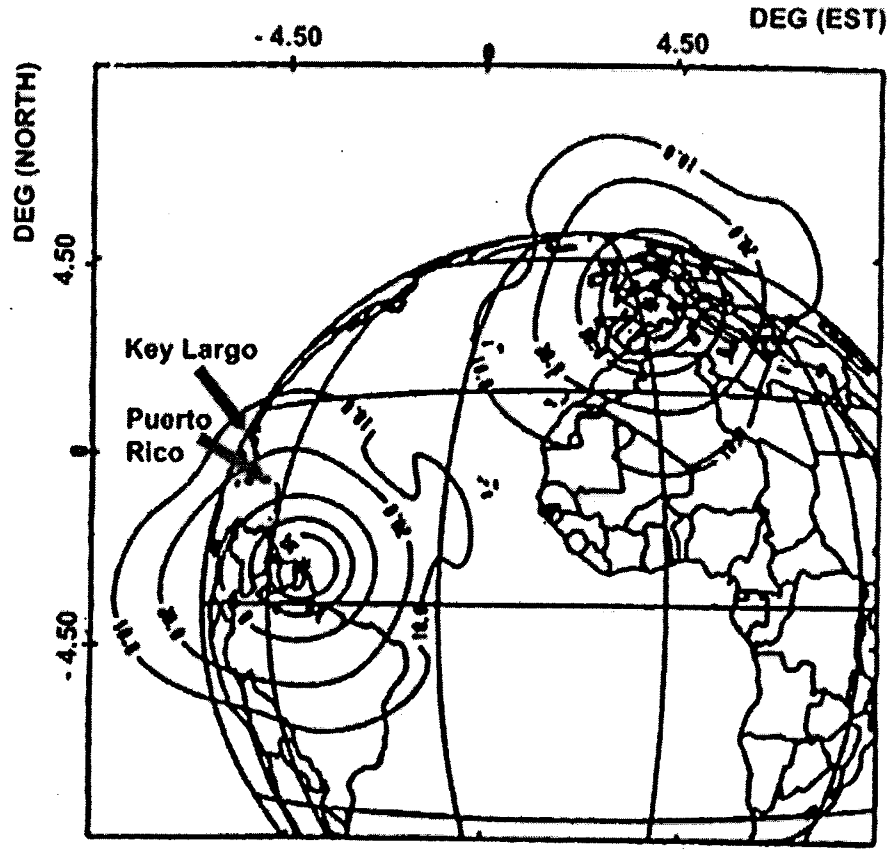
STENTOR
41.4 GHz Spot Beam



STENTOR RX d = 200 f/d = 1 Pertes - 2.30 dB

FREQUENCY 41400. MHz
MAX 34.80 dB

STENTOR
20.7 GHz Spot Beam



STENTOR TX d = 450 F/D 0.8 PERTES -1.65 dB
FREQUENCY 20700. Mhz
MAX 36.20 dB

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STENTOR-Ground Segment

Description: *Modified ACTS Reflector with offset feed receiving beacons at 20.7GHz and 41.4GHz*

- **Determine Location (Florida, Puerto Rico)**
- **Determine Link Budget for each possible location**
- **Determine Antenna Hardware Modifications**
- **Determine Software Modifications**

STENTOR-Ground Segment Location

Possible Sites	Elevation Angle	Azimuth
Miami , FL	10.1	-80.6
Key Largo, FL	10.0	-81.0
Keywest, FL	8.8	-81.8
San Jaun, PR	25.0	-77.5

STENTOR-Ground Segment Preliminary Power Budget

Parameter	Units	S. Florida (Gs=0-10dB)		Puerto Rico (U.S)(Gs=20-25dB)	
Frequency	GHz	41.4	41.4	41.4	41.4
Transmit Antenna Gain	dBi	5	10	20	25
EIRP	dBW	-3.3	1.7	11.7	16.7
Modulation Loss	dB	0	0	0	0
Pointing Loss	dB	0.1	0.1	0.1	0.1
Path Loss	dB	217.0	217.0	216.6	216.6
Clear Sky Attenuation	dB	4.0	4.0	1.7	1.7
Fading allowance	dB	0	0	0	0
Antenna Efficiency	%	55	55	55	55
Antenna Gain(1.22m)	dB	52.5	52.5	52.5	52.5
Antenna Temperature	K	100	100	100	100
Polarization mismatch	dB	-3.0	-3.0	-3.0	-3.0
Net Losses	dB	166.2	166.2	163.6	163.6
Power Available	**dBW**	**-172.5**	**-167.5**	**-154.9**	**-149.9**
Power from ACTS at 20.185 GHz in Blacksburg				**-147.3**	**dBW**

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STENTOR-Ground Segment
Preliminary Power Budget

Parameter	Units	S. Florida (Gs=10-15dB)		Puerto Rico(Gs=20-25dB)	
Frequency	GHz	20.7	20.7	20.7	20.7
Transmit Antenna Gain	dBi	10	20	25	28
EIRP	dBW	-1.6	8.4	13.4	16.4
Modulation Loss	dB	0	0	0	0
Pointing Loss	dB	0.1	0.1	0.1	0.1
Path Loss	dB	211.0	211.0	210.6	210.6
Clear Sky Attenuation	dB	3.7	3.7	1.6	1.6
Fading allowance	dB	0	0	0	0
Antenna Efficiency	%	55	55	55	55
Antenna Gain(1.22m)	dB	46.6	46.6	46.6	46.6
Antenna Temperature	K	100	100	100	100
Polarization mismatch	dB	-3.0	-3.0	-3.0	-3.0
Net Losses	dB	165.9	165.9	163.5	163.5
Power Available	**dBW**	**-170.5**	**-160.5**	**-153.1**	**-150.1**
Power from ACTS at 20.185 GHz in Blacksburg				**-147.3**	**dBW**

STENTOR-Ground Segment Receiver Modifications (Future)

- **Determine Necessary Modifications**
  - ✶ Hardware Modifications(LNA, Frequency Multiplexiers, DRX, Dish, etc.) - TBD
  - ✶ Antenna Noise -TBD
  - ✶ Phase Difference Measurements -TBD